

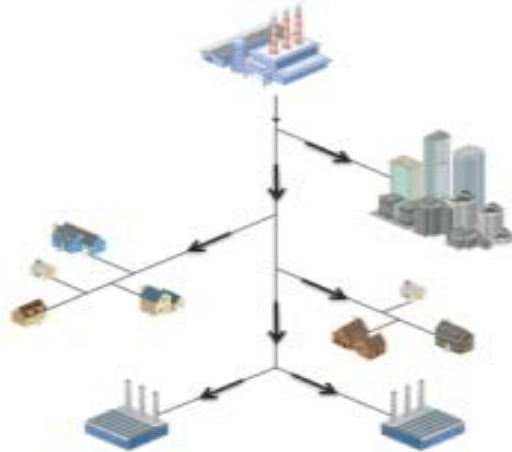


Energy Systems Integration Facility

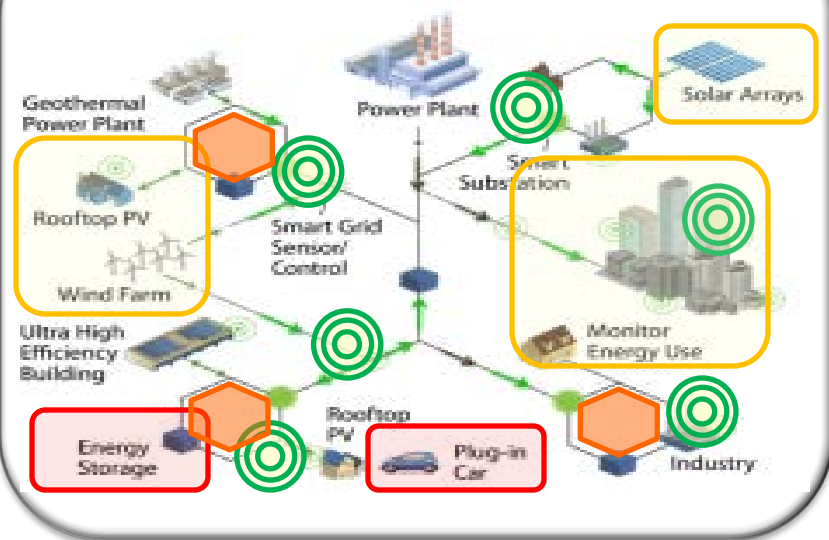
Ben Kroposki, PhD, PE
Director, Energy Systems Integration
National Renewable Energy Laboratory

Why Energy Systems Integration?

Current Energy Systems



Future Energy Systems



Reducing investment risk and optimizing systems in a rapidly changing energy world

- Increasing penetration of variable RE in grid
- Increasing ultra high energy efficiency buildings and controllable loads
- New data, information, communications and controls
- Electrification of transportation
- Integrating energy storage (stationary and mobile) and thermal storage
- Interactions between electricity/thermal/fuels
- Increasing system flexibility and intelligence

ESIF System Integration Capabilities

Energy System Research and Development Across Technologies



Solar and Wind

- RE integration
- Power electronics
- Building integration
- Thermal and PV system optimization



Grid Planning and Operations

- Transmission and Distribution Systems
- Smart Grid Technologies
- Microgrids
- Standards



Energy Storage

- CSP Thermal Storage
- Utility scale batteries
- Distributed storage



Buildings

- Sensors and controls
- Design and integration
- Modeling and simulation
- Big Data warehousing and mining
- System integration



Fuel Cells and Hydrogen

- H₂/electric interfaces
- RE electrolyzers
- Storage systems
- Standards
- Fuel cell integration
- Fueling systems



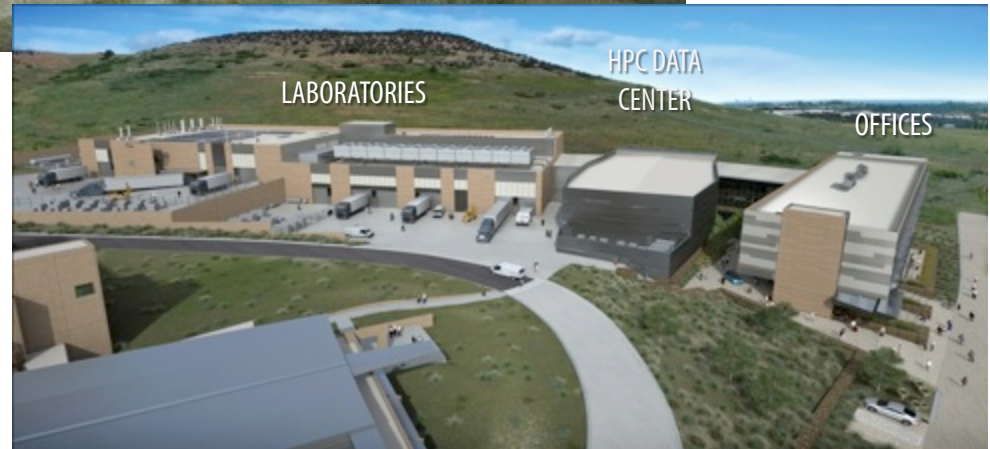
Advanced Vehicles

- Plug-in-hybrids and vehicle-to-grid
- Battery thermal management
- Power electronics

Full systems interface evaluation for integration of electricity, fuels, thermal, storage, and end-use technologies

NREL's Energy Systems Integration Facility (ESIF)

- NREL's largest R&D facility (182,500 ft²)
- Space for 200 NREL staff and research partners
- Focus of the ESIF is to conduct R&D of integrated energy systems (Electricity, Fuels, Transportation, and Buildings & Campus systems)



Addressing the challenges of large-scale integration of clean energy technologies into the energy systems infrastructure

http://www.nrel.gov/eis/facilities_esif.html

Current Status and Construction Targets

- **October 2012 – substantial completion**
- **November 2012 – commissioning and move-in**
- **January 2013 – complete move**
- **DOE Programs moving into ESIF**
 - Solar – Systems Integration, CSP
 - Wind - Systems Integration
 - Fuel Cell Technologies
 - Buildings
 - Vehicles (lab testing)
 - Office of Electricity
 - Scientific Computing



ESIF - Office Area

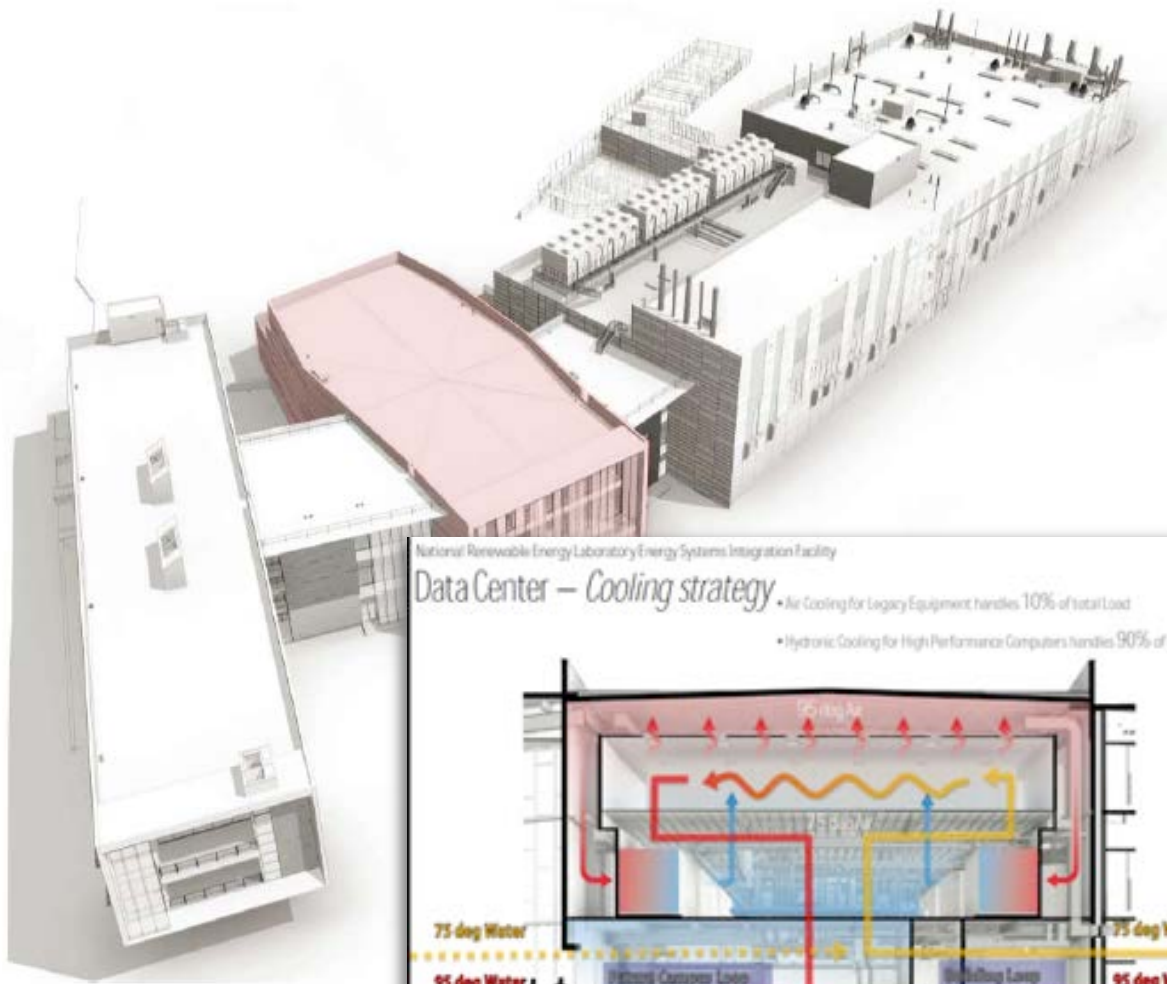
National Renewable Energy Laboratory Energy Systems Integration Facility

Office Space

- Energy Target (Site EUI): 26.7 kBtu/sf/yr
- National Average Site EUI: 90 kBtu/sf/yr (CBECS)
- Energy Efficiency over National Average (w/server): 74%
- Energy Efficiency over National Average (w/out HPC): 87%



ESIF - High Performance Computing Data Center



Showcase Facility

- Use evaporative rather than mechanical cooling.
- Waste heat captured and used to heat labs & offices.
- **World's most energy efficient data center, PUE 1.06!**

20 year planning horizon

- 5 to 6 HPC generations.

Energy Data Hub

- Data mgmt, mining, analytics
- Smartgrid.gov
- High frequency data from technology deployment

Insight Center

- Scientific data visualization
- Collaboration and interaction.

PUE = Power Usage Effectiveness

ESIF's Unique Advanced Capabilities

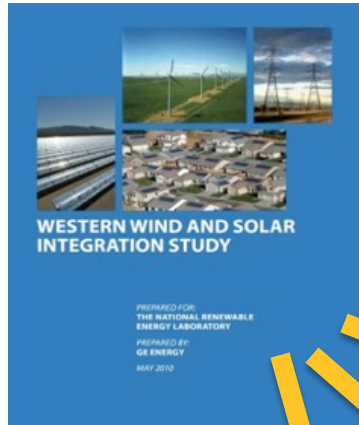


- Petascale HPC and data management system in showcase energy efficient data center.
- Virtual utility operations center and visualization rooms to understand impact of high penetration variable renewables, electric vehicle, and energy efficiency deployments.
- Interconnectivity to external field sites for data feeds and model validation.



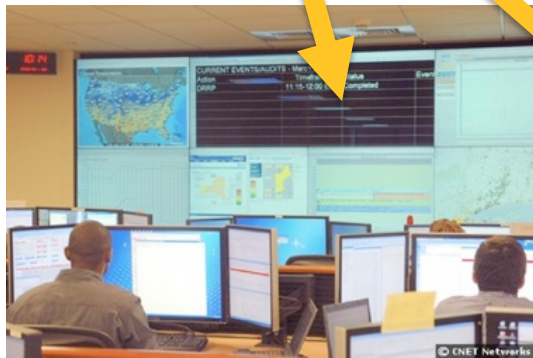
ESIF - Energy System Simulated Operations

A Flight Simulator for Energy System Operators
"connecting integration studies to operations"

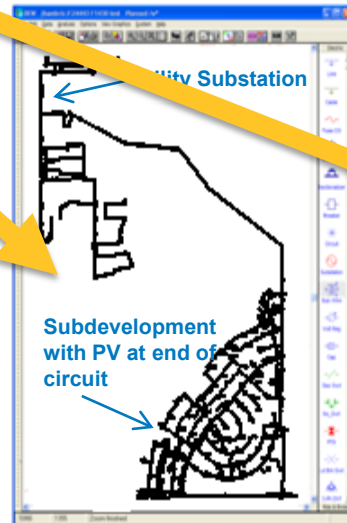


Operations techniques development for:

- High renewables and energy efficiency penetrations
- New systems configurations and contingency response
- High storage / DR penetrations
- Resource forecast integration



Transmission

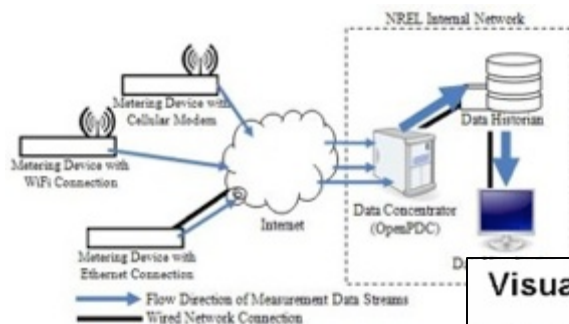


Distribution

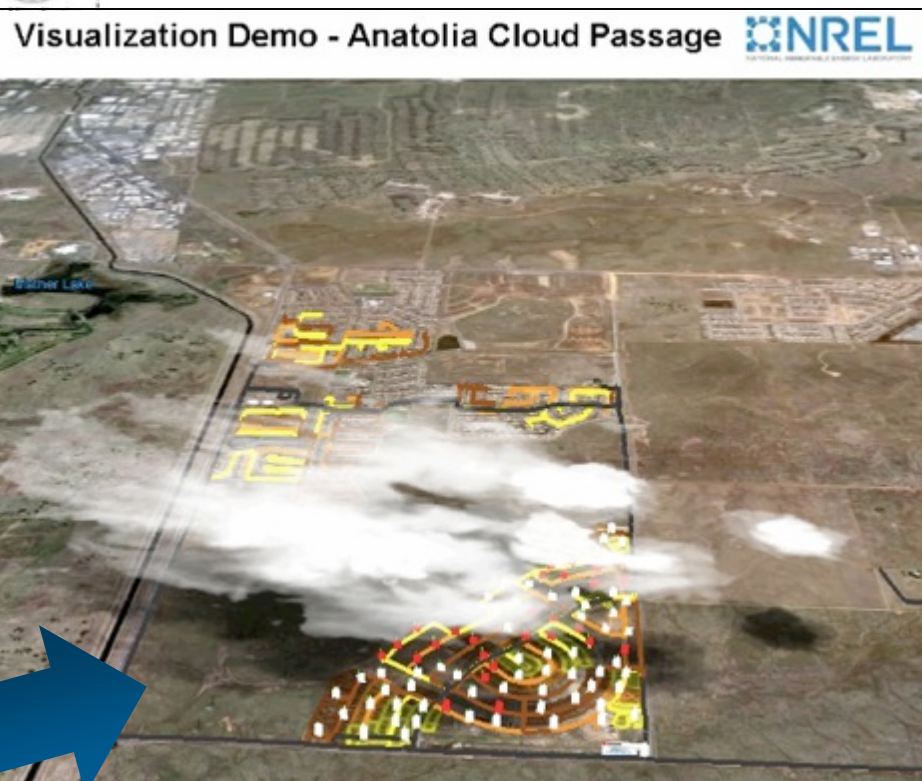


Campus Energy Dashboard

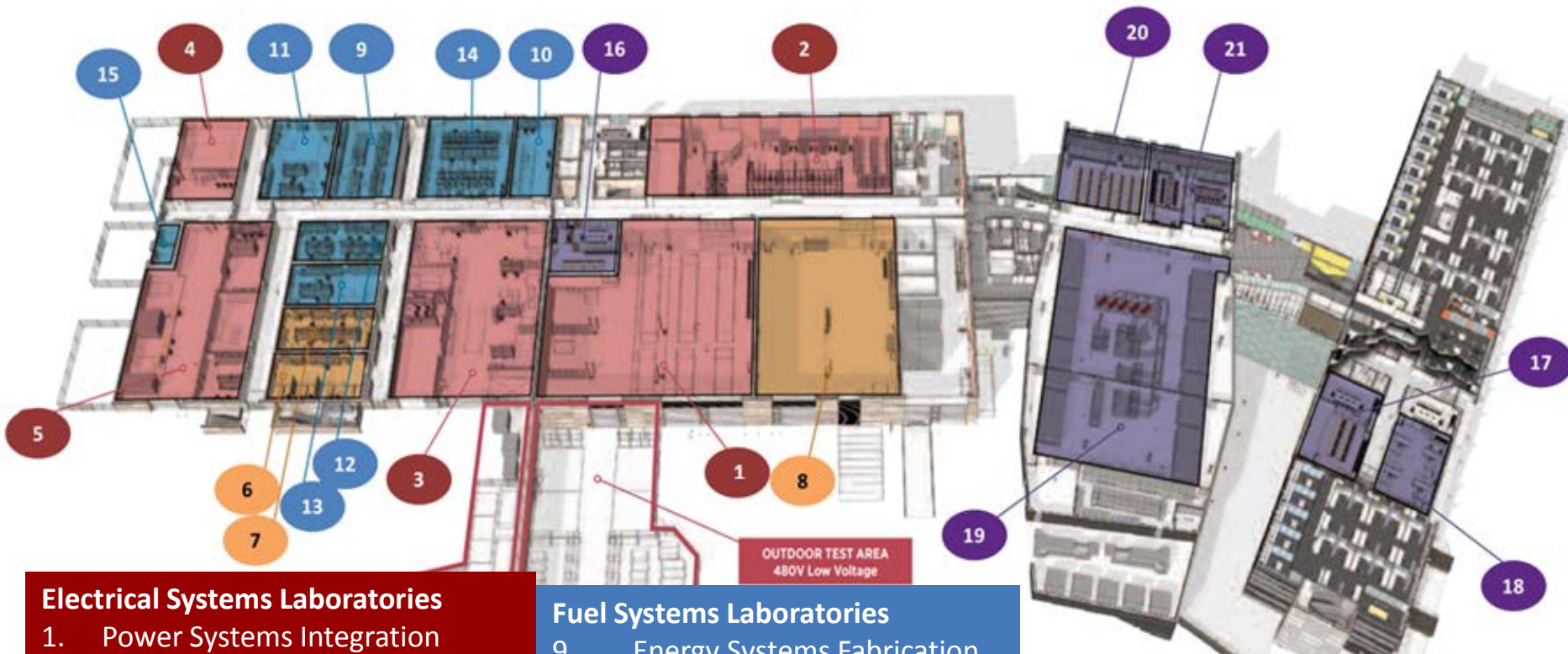
ESIF - Energy System Visualization



NREL is working with SMUD on visualizing impact of DG deployments



ESIF Laboratories



Electrical Systems Laboratories

1. Power Systems Integration
2. Smart Power
3. Energy Storage
4. Electrical Characterization
5. Energy Systems Integration

Thermal Systems Laboratories

6. Thermal Storage Process and Components
7. Thermal Storage Materials
8. Optical Characterization

Fuel Systems Laboratories

9. Energy Systems Fabrication
10. Manufacturing
11. Materials Characterization
12. Electrochemical Characterization
13. Energy Systems Sensor
14. Fuel Cell Development & Test
15. Energy Systems High Pressure Test

High Performance Computing, Data Analysis, and Visualization

16. ESIF Control Room
17. Energy Integration Visualization
18. Secure Data Center
19. High Performance Computing Data Center
20. Insight Center Visualization
21. Insight Center Collaboration

ESIF Labs - Interior



Smart Power Lab

Energy Systems Integration Lab



ESIF Research Infrastructure

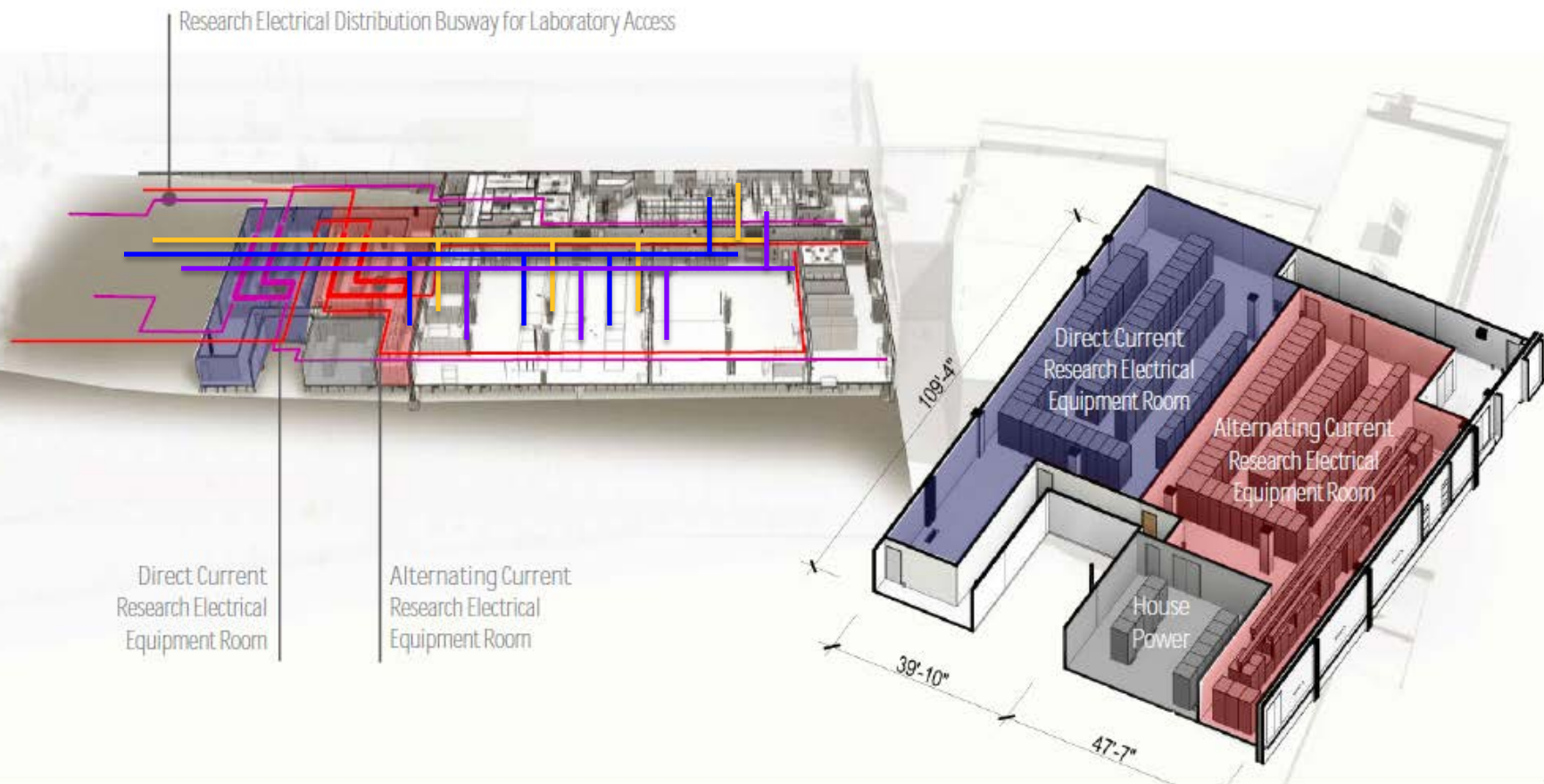
🔌 Research Electrical Distribution Bus – REDB (AC 3ph, 600V, 1200A and DC +/-500V, 1200A)

🔥 Thermal Distribution Bus

💧 Fuel Distribution Bus

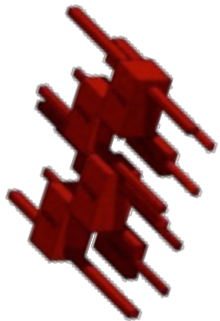
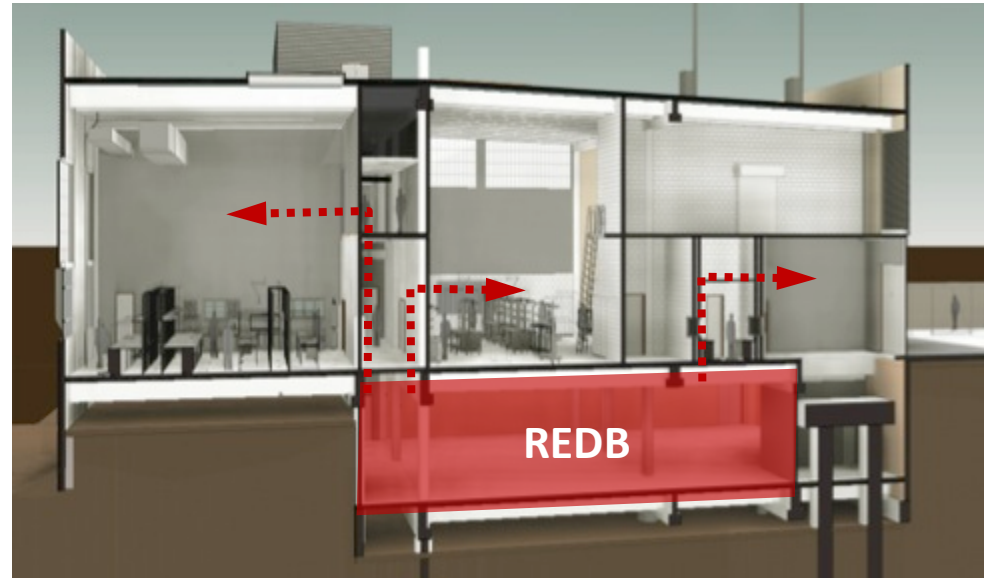
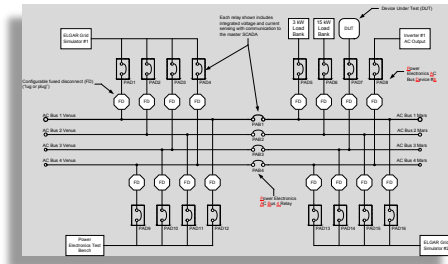
🕸 Supervisory Control and Data Acquisition (SCADA)

- Utility Scale Research
- 1.5 MW – Single Source REDB
- 1 M – Micro Grid Simulation



ESIF's Unique Advanced Capabilities

- Multiple parallel research electrical distribution busses (REDB) at MW power level with grid and load simulation.



- Flexible interconnection points for electricity, thermal, and fuels to multiple labs.
- Medium voltage (15kV) microgrid test bed.
- Extensive selection of existing distributed energy systems and high power PV and wind simulation.

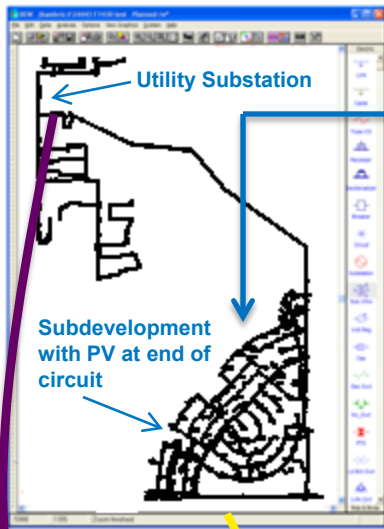
ESIF - Hardware-in-the-Loop (HIL)

Simulation validated
with real field data

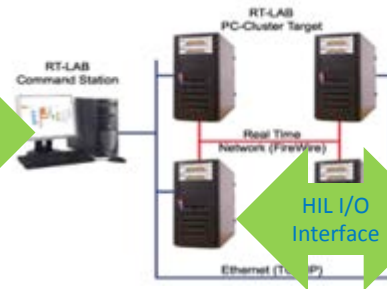


Actual hardware at ESIF

Simulation and Visualization at ESIF



Visualization
Interface

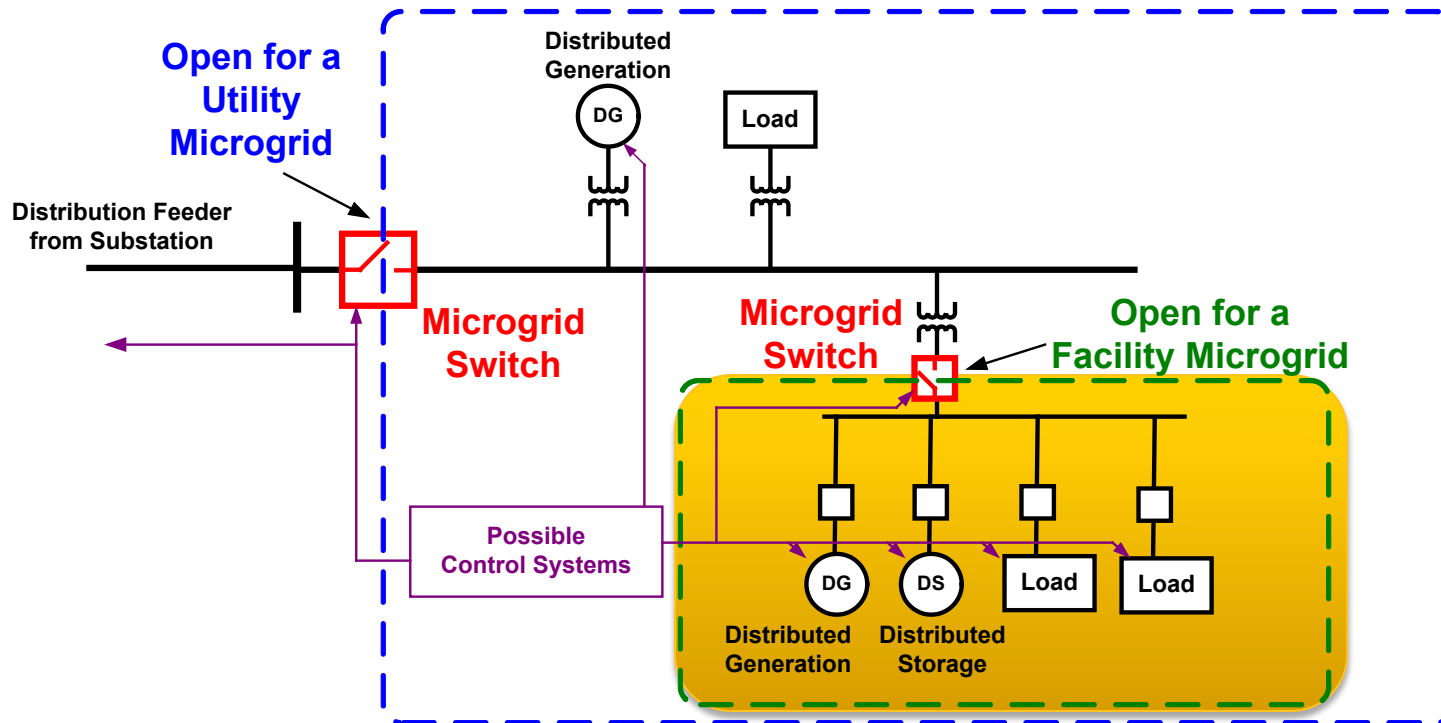


Replicated into
Larger Simulation



Simulation loop
closed with actual
hardware

MICROGRID BASICS



**IEEE 1547.4 Guide for Design,
Operation, and Integration of
Distributed Resource Island Systems
with Electric Power Systems –
Completed July 2011**

DR island systems are parts of electric power systems (EPSs) that have DR and load, have the ability to disconnect from and parallel with the EPS, include the local EPS and may include portions of the area EPS, and are intentional and planned.

http://www.nrel.gov/eis/facilities_esif.html

- **Distributed Energy Resources Test Facility (DERTF)**

- Testing microgrids up to 200kW
- Grid Simulators, Load Banks, actual wind turbines and PV systems available



- **Energy Systems Integration Facility (ESIF)**

- Opens October 2012
- Low Voltage (600V and Under) and Medium Voltage (15kV and Under) test areas
- Flexible connections for electrical, thermal, and fuel infrastructure



- **National Wind Technology Center (NWTC)**

- 7MW grid simulation
- access to MW scale wind turbines
- MV distribution system

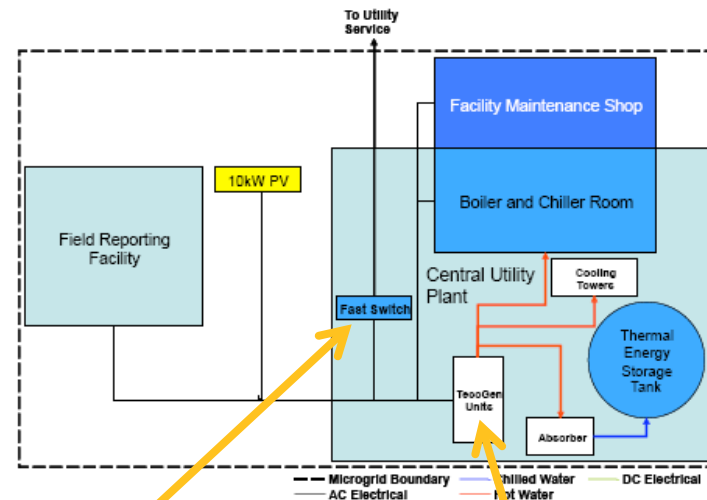


CERTS MicroGrid Concept Demo at SMUD

- Sacramento Municipal Utility District (SMUD) is installing a microgrid at their headquarters
- NREL completed testing of newly developed microgrid switch technology from Cyberex and two 100kW Tecogen CHPs with inverter/droop control
- NREL power testing of microgrid configurations reduces risk of operational performance

SMUD Microgrid Project Overview

310kW demo Microgrid concept



Installation at the NREL DERTF

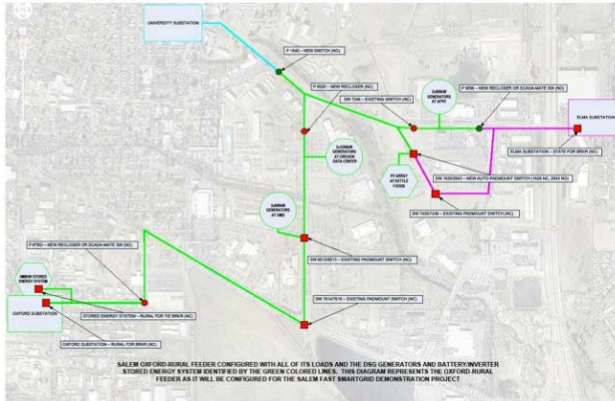


Tecogen CHP modules (2)

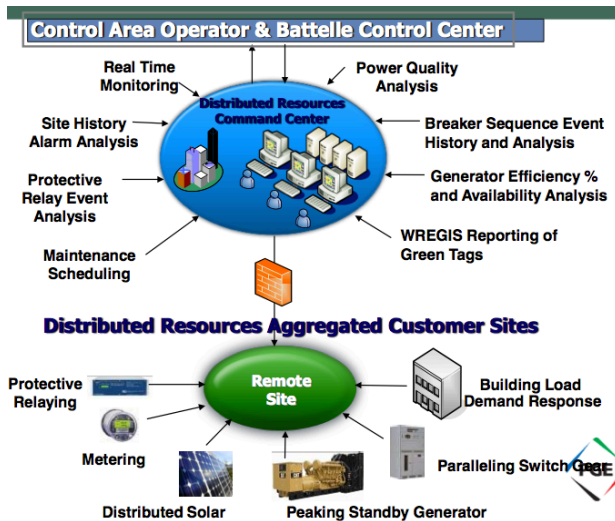
Air Handling Units
(2) X 120 ton for engine
(2) X 50 ton for generator/PE

Portland General Electric

High Reliability Zone Map



Smart Inverter



Energy Storage

Portland General Electric

- **Performance Testing**

- Inverter, Battery, Generators - Basic operational functions (e.g. Energize, sync. with grid, etc.) Test of basic operating modes (current control, droop, etc.) and states (offline, ready, on grid discharge, etc.) Test of basic inverter paralleling operation

- **Systems Integration and Transition Testing**

- Confirm everything working together, verify that key system functions like picking up the load immediately after the grid disconnects work). Test of key transitions between basic states (offline, on-grid (w/ or w/o gen), off-grid (w/ or w/o gen), etc.) Proper sequencing of transitions from island mode to grid-connect mode without disturbances

- **Fault Testing**

- Test the fault contribution of the inverter to high and low impedance faults and its interaction with typical lateral protection devices (mostly fuses)

Thank you

Ben Kroposki

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National Renewable Energy Laboratory

For more information on NREL Integration Projects and ESIF:

http://www.nrel.gov/eis/facilities_esif.html